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Abstract

Many different vendor selection models have been published in the purchasing literature. However there has been no systematic approach to compare the relative efficiency of the systems. In this paper we propose to use the concept of Total Cost of Ownership as a basis for comparing vendor selection models. We illustrate the comparison with the real life data set of the purchasing problem of ball bearings at Cockerill Sambre, a Belgian multinational company in the steel industry. Mathematical programming models outperform rating models and multiple item models generate better results than single item models from a Total Cost of Ownership perspective for this specific case study.

Keywords: Purchasing, Management Accounting/Operations Research

1. Introduction

In the literature (Dickson, 1966; Weber, Current and Benton, 1991) several dimensions are mentioned that are important for the multiple objective vendor selection decision. These include net price, quality, delivery, performance history, capacity, communication system, service, geographical location, etc. The problem is how to select suppliers that perform satisfactory on the desired dimensions. The published vendor selection decision models formulate answers to this multiple objective problem. Some authors propose linear weighting models in which suppliers are rated on several criteria and in which these ratings are combined into a single score. Others propose mathematical programming formulations in which quantifiable criteria are taken into account. Some

approach the problem on an item-by-item basis, others consider it a multiple item decision. Only a few authors incorporate the inventory management issue into the supplier selection decision.
No research has been done on how to compare these different approaches to vendor selection and to find out the "best" way to handle the decision. The problem is to find a basis for comparison that is theoretically sound. In this paper we propose the concept of Total Cost of Ownership (TCO) to compare the relative efficiency of different vendor selection decision models. The Total Cost of Ownership quantifies all costs associated with the purchasing process throughout the entire value chain of the firm. We apply each of the vendor selection models proposed in the literature to the real life data set of the purchasing problem of ball bearings at Cockerill Sambre. Subsequently, we calculate the Total Cost of Ownership of the resulting solutions, i.e. choices of what to buy from whom and when. In this way, we are able to evaluate and compare the existing vendor selection models from a Total Cost of Ownership perspective.

The contribution of this paper is fourfold. First, we present a classification of published vendor selection models. Second, these models are evaluated from a Total Cost of Ownership perspective. Third, the application and evaluation of the different vendor selection models is done using a real life data set of the purchasing problem of ball bearings at Cockerill Sambre. The data consist of information on various criteria other than the classical quality, time and quantity discount parameters. Fourth, several conclusions will be drawn regarding the efficiency of the different kinds of vendor selection models.

The remainder of the paper is organised as follows. In section 2, the Total Cost of Ownership perspective from which the evaluation will be made and all parameters associated with it, are explained. Section 3 will discuss the classification of the vendor selection models. In section 4 we describe the real life case used to evaluate the published vendor selection models. In the fifth section the results of the comparison will be discussed. Finally, in section 6, we will draw conclusions and make suggestions for future research.

2. The Total Cost of Ownership Approach

The Total Cost of Ownership quantifies all costs associated with the purchasing process throughout the entire value chain of the firm. The cost of the acquisition and subsequent use of an item or service that is to be purchased is determined. The approach goes beyond price to consider all costs over the items' entire life such as those related to service, quality, delivery, administration, communication, failure, maintenance,...(Ellram, 1994, 1995b). The analysis of costs throughout the extended value chain of a company is an important topic in today's management accounting literature (Shank and Govindarajan, 1992). Activity Based Costing (ABC) permits us to analyse activities and determine cost drivers for the different activities defined. While suppliers are an important part of the total value chain, the application of Activity Based Costing ideas to the vendor selection problem has received little attention. Roehm, Critchfield and Castellano (1992) discuss the use of the system in a purchasing department. They assign additional purchasing costs to products, but not to suppliers. Ellram (1995a) and Roodhooft and Konings (1997) develop the link between the selection of suppliers and Activity Based Costing. Also Carr and Ittner (1992), Cavinato (1992) and Ellram and Siferd (1993) elaborate on the use of the TCO concept in purchasing.

Degraeve and Roodhooft (1996) recognise a hierarchical structure in activities with respect to the purchasing problem: (1) the supplier level, (2) the order level and (3) the unit level activities. The first hierarchical level describes costs incurred and conditions imposed whenever the purchasing company actually uses the supplier over the decision horizon. Examples of costs on the supplier level include quality audit cost incurred by the buyer for the evaluation of a supplier, cost of a dedicated purchasing manager and additional research and development costs due to using a particular supplier. The order level parameters indicate costs incurred and conditions imposed each time an order is placed with a particular supplier and include, amongst others, costs associated with reception, invoicing, transportation, ordering and receiving credit notes. On the unit level we find costs incurred and conditions imposed related to the units of the products for which the procurement decision has to be made, for example, set up, defects, external failure and inventory holding. It is important to make this classification of activities into separate levels since the overall cost driver (number of suppliers, number of orders, number of units procured) for each level of activity is independent of the activities in other levels.

The use of Activity Based Costing in supplier selection models has several advantages. First, it is important to note that the quantification of the criteria and the trade-off between them is no longer a problem because the objective function is defined as the Total Cost of Ownership with respect to the purchasing decision caused by the suppliers. Second, an important advantage of this approach over other methodologies exists in arriving at objective cost measures in a systematic way. Third, the system will enable companies to develop interorganisational activity based management opportunities given the importance of close relationships between the purchaser and a limited number of reliable suppliers. Fourth, the model allows us to answer all sorts of "what if" questions dealing with cost management and strategic decision making such as (1) the cost impact of making different/alternative supplier selections, (2) the consequences of performance improvement by suppliers with respect to different important criteria and the reduction or elimination by the purchasing company of some of the costs or activities caused by the purchasing decision and (3) the evaluation of alternative company policies with respect to the number of suppliers, order quantities and minimum and/or maximum quantities to buy. A disadvantage of the approach is that determining the Total Cost of Ownership of selecting a supplier for the delivery of a certain item based on ABC information requires an extensive management accounting system that captures the relevant costs of the activities by supplier and item purchased.

In the following sections we discuss the different vendor selection models more thoroughly and evaluate them from a Total Cost of Ownership viewpoint whenever the Cockerill Sambre ball bearings data set allows us to do so. First, we have applied the different vendor selection models to the data set using the advocated methodology while trying to stay as close as possible to the philosophy of the authors. Then the Total Cost of Ownership resulting from the vendor selection and inventory management models, i.e. combinations of what to buy, from whom and when is computed. These are compared to the solution that minimises Total Cost of Ownership (Degraeve and Roodhooft, 1996) and to the other vendor selection models. When a model only gives a solution to the vendor selection problem, i.e. what to buy from whom, the Total Cost of Ownership is calculated under two different assumptions. First it is assumed that all orders for the full time horizon are placed in the first period. Subsequently we assume a Total Cost of Ownership-optimal inventory policy, where only what to buy from whom is fixed using the original vendor selection model. This second assumption gives the maximum possible credit to the vendor selection model that is compared to the Total Cost of Ownership approach. When a single item model is to be compared, we have applied it iteratively to the ball bearings case in order to find a solution for the multiple item problem.

3. Classification of Vendor Selection Decision Models

As reported in table 1, a division can be made between single item (Timmerman 1986, Gregory 1986, Barbarosoglu and Yazgaç 1997, Willis et al. 1993, Li et al. 1997, Soukup 1987, Thompson 1990, Chaudry et al. 1993, Weber and Current 1993, Weber and Desai 1996) and multiple item models (Grando and Sianesi 1996, Turner 1988, Current and Weber 1994, Akinc 1993, Sadrian and Yoon 1994, Rosenthal et al. 1995, Benton 1991, Bender et al. 1985, Degraeve and Roodhooft 1996, Ronen and Trietsch 1988) . Single item models select vendors for one product, but fail to take into account the interdependencies among the different products. A supplier can be offering a larger discount based on total sales volume, irrespective of the product mix. Order level costs could be minimised by combining orders for several products into one single order form. Single item models also underestimate the supplier level costs that arise because of working with a supplier (e.g., plant visit, purchasing manager's time to negotiate). Moreover, those costs are often completely disregarded. More than half of the vendor selection models handle the problem on an item-by-item basis and have to be applied iteratively to select suppliers for multiple items.

-insert table 1 about here-

Most of the existing literature treats vendor selection without inventory management. It could be argued that purchasing managers should incorporate the decision to schedule orders over time with the vendor selection decision. For example, at the order level, costs can differ substantially between the different possible suppliers due to the possibility of ordering via Electronic Data Interchange (EDI). If, due to inventory management reasons frequent ordering is necessary, a supplier with a low unit price but a high order cost e.g., no EDI, can generate a higher Total Cost of Ownership than a supplier with a higher unit price and an EDI-system. Another example is the trade-off between the receiving a quantity discount and the inventory holding costs when buying larger lotsizes. It should be noted that, to our knowledge, no single item models with inventory management over time exist, except for Degraeve and Roodhooft (1998), but this is in fact the multiple item model of Degraeve and Roodhooft (1996) applied to the single item purchasing case of heating electrodes at Cockerill Sambre.

To our knowledge, Degraeve and Roodhooft (1996) is the first model that makes the widely accepted theoretical construct (e.g. Ellram, 1995a&b) of Total Cost of Ownership operational in a purchasing context and uses Activity Based Costing and Total Cost of Ownership information in an objective mathematical programming model to simultaneously select vendors and determine order quantities for multiple items over a multiple period time horizon. The model is programmed in LINGO and solved on a Pentium with 16 Mb RAM in 43 minutes for the case of the ball bearings. Apart from Degraeve and Roodhooft (1996), only Bender, Brown, Isaac and Shapiro (1985) and Ronen and Trietsch (1988) deal with inventory management over time and vendor selection in one model. Bender et al. do not include the mathematical programming model in their paper. Ronen and Trietsch propose a decision support system that selects suppliers and schedules order placements over time, but that is focusing on the lead time management of large projects. In this specific situation there is a demand for a particular item at only one moment in time, fixed via the PERT environment in which the DSS is embedded. The inventory management problem here is essentially answering the question for every item "how long before the due date will the order have to be placed?"

A third distinction exists between rating/linear weighting models, mathematical programming models and statistical models. Rating models (Timmerman 1986, Gregory 1986, Barbarosoglu and

Yazgaç 1997, Willis et al. 1993, Li et al. 1997, Soukup 1987, Thompson 1990, Grando and Sianesi 1996) are very subjective and often very sensitive to different rating scales, weights and/or ratings by other people. Most of the linear weighting models are compensatory, though some are non-compensatory (Grando and Sianesi 1996). In a compensatory model a low rating on one criterion can be compensated by a high rating on another criterion, whereas in non-compensatory models different minimum levels for each criterion are required. Soukup (1987) and Thompson (1990) include uncertainty with respect to certain features of the problem in their rating models. Mathematical programming models (Chaudry et al. 1993, Weber and Current 1993, Weber and Desai 1996, Turner 1988, Current and Weber 1994, Akinc 1993, Sadrian and Yoon 1994, Rosenthal et al. 1995, Benton 1991, Bender et al. 1985, Degraeve and Roodhooft 1996) often consider only the more quantitative criteria. They can be subdivided in linear, (mixed) integer or goal programming models. Statistical models (Ronen and Trietsch 1988) incorporate uncertainty into the vendor selection decision.

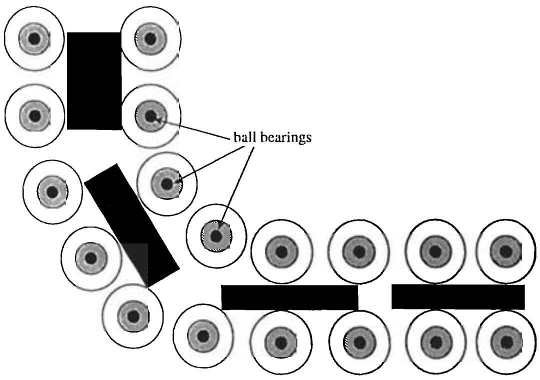
Some of the vendor selection models could not be applied to the problem of the ball bearings procurement at Cockerill Sambre because of data availability or applicability reasons. Barbarosoglu and Yazgaç (1997) use the analytic hierarchy process for the vendor selection problem following Narasimhan (1983). They list in a "structured subjective way" many criteria that are weighted relative to the importance attached to them by several specialists from different subfields in the company. To evaluate this paper this process should have been carried out by different managers at Cockerill Sambre, which was impossible. Soukup (1987) introduces uncertainty with respect to the requirements patterns in a single item rating model without inventory management. The forecasting of the market probabilities remains a subjective process. We are not able to apply this approach to the Cockerill Sambre case since the necessary data are not available. Grando and Sianesi (1996) develop a multiple item rating model to help visualise possible vendor selection strategies. The different criteria are assessed on the basis of historical longitudinal data that are not available for the Cockerill Sambre ball bearings case either. Although the model could be used non-compensatory the authors propose to give weights to each of the indices to get a single rating for each supplier. To apply the Ronen and Trietsch (1988) decision support system to the vendor selection and inventory management problem the distribution of the lead time has to be known. The authors assume an exponential distribution for simplicity but contend that in practice the distribution can be deduced from historical data. It seems to us that in the context of large one-off projects this could pose severe problems. Bender, Brown, Isaac and Shapiro (1985) describe a mixed integer programming model used at IBM that simultaneously selects vendors and determines order quantities over a multiple time frame horizon with the objective to minimise purchasing, inventory management and transportation costs. We cannot evaluate this model since the specific mathematical formulation is not included in their paper.

4. The Problem of Purchasing Ball Bearings at Cockerill Sambre

We study the procurement of ball bearings at Cockerill Sambre S.A., a Belgian multinational company in the steel industry with external purchases approaching £0.6 billion annually accounting for more than 70 % of total costs. Management wants to improve the efficiency of the purchasing process and to reconsider the sourcing strategies for different product groups. Our case study refers to the ball bearings, a product selected for study by the purchasing managers of the firm and a business of about £833,000.- per year. There are 33 ball bearings types in the problem for which purchasing decisions must be made.

The ball bearings are mainly used for transportation of the hot steel slabs after steel has been produced in the converters and cast to form the slabs. The transportation lines consist of several rows of vertical steel cylinders as depicted in figure 1.

Figure 1 : Usage of the Ball Bearings.



The steel cylinders and the ball bearings are used in very arduous conditions under extremely high temperatures. This causes the surface of the steel cylinders to deteriorate quickly such that they have to be replaced frequently and brought to a maintenance department for reprofiling. At the time of replacement of the cylinders, the ball bearings are also replaced in anticipation of potential problems and thus before they have been used for their full lives. There is a revenue associated with used ball bearings based on their weight, amounting to £100.- per ton. There are 6 possible suppliers, two of which are currently used by the company. Important price differences exist at the level of the individual ball bearing type. No quantity discounts apply to this product group.

Whereas the literature (Dickson, 1966; Weber, Current and Benton, 1991) mentions a variety of dimensions which could be considered in vendor selection, the presented evaluation of vendor selection models is based on the case of ball bearings and does encompass only the criteria relevant to this purchasing problem. The dimensions on which the suppliers differ from each other are price, possibility to deliver a certain item, service level, cost of the purchasing manager to establish a relationship with a certain supplier, the possibility of EDI, the reliability of delivery visualised by the need to maintain a safety stock and the terms of payment. The more traditionally used dimensions of quality, lead time management and quantity discounts are not relevant to this case. The duration of life of the steel cylinders is shorter than that of the ball bearings, but the ball bearings are replaced every time a cylinder is changed, before they are worn out. Therefore quality is not a crucial issue in the case of the ball bearings. Lead time is the same for all possible suppliers. There are no quantity discounts available. For the ball bearings' problem specifically we consider on supplier level the cost of a dedicated purchasing manager and a discount resulting from service provided by the supplier. What is specific to this case study is that there is a return instead of a cost on supplier level because the service provided by the supplier exceeds the cost of the purchasing manager. The order level costs include invoice cost per order, order cost per order and reception cost per order. At the unit level we find in this case the salvage value of the used ball bearings, the price of the ball bearings, the price discount as a percentage per time bucket due to payment delay given by a particular supplier and the inventory holding cost.

5. Results of Comparison from a Total Cost of Ownership Perspective

In table 2, we summarise the resulting Total Cost of Ownership for the solutions of the different vendor selection problems. The second column gives the Total Cost of Ownership in percentages of the results of the TCO minimising Degraeve and Roodhooft (1996) model. The third, fourth and fifth column give the three components of the TCO, namely supplier level cost, order level cost and unit level cost in percentages. Observe that there is a return (or negative cost) on the supplier level in this case.

-insert table 2 about here-

Almost half of the evaluated vendor selection models are single item rating / linear weighting models. Timmerman (1986) proposes "linear averaging" in the case of medium-sized manufacturers. For the application to the ball bearings case we have used as cost items the price and the payment delay. Service includes technical assistance, education, buy back and recycling of scrap, competence and swiftness of intervention, additional work for the purchasing manager and the administrative costs of ordering and paying, rated by the purchasing managers of Cockerill Sambre. No product specific items are taken into account since for this specific case there are no differences in the quality of the products for different suppliers. To get a rating on the price component we used the method of Zenz (1994, pp.135-136) who uses lowest price divided by actual price multiplied by maximum rating. A problem not treated in Timmerman (1986) is what to do when two or more suppliers receive the same rating for a specific item. To evaluate the model from a TCO perspective we have used three assumptions to solve the problem: (1) the orders are split so that each supplier gets 1/x of the order with x the number of suppliers receiving the same maximum rating for the item; (2) the whole order is given to the supplier with the lowest price of those who attain the maximum rating and (3) we have only constrained the choice of the supplier(s) to those receiving the maximum rating and let the TCO model optimise the decision. Again, this assumption gives the most credit to the supplier selection model studied. As we can see in table 2, the TCO of Timmerman (1986) varies, depending on the assumptions between 107,5 and 115,5 % of the TCO minimising model. This illustrates the advantage in TCO of including inventory management in the supplier selection decision. In the sensitivity analyses we have counted how many item-supplier combinations changed in comparison to those of the original model when changing weights and rating limits. Although Timmerman (1986) is not sensitive to changes of weights within a certain category like service, we have observed that it is very sensitive to changes in weights across categories and to changes in rating limits. Investigating the impact of such changes, we observed in our computational experiments that up to halve of the items were ordered from a different supplier.

Gregory (1986) describes the vendor rating system used by Texas Instruments, that again works with weights on two levels. He recognises five main categories, each divided into subcategories. For our application we use, in the “proposal responsiveness category”, ratings on terms and conditions and on timeliness of deliveries. In the “quality / reliability category” we make two subcategories that are relevant for the case: experience with the company and electronic data interchange (EDI). In the “cost category” we rate the unit price, again using Zenz’ method. The “general category” encompasses ratings on past delivery history and payment provisions. In our case there is no “technical category” since all products have the same specificity and quality. In contrast to Timmerman, Gregory proposes two methods for order splitting. When applying the method to the ball bearings case no two suppliers received the same maximum rating. From table 2 we see that the TCO of Gregory (1986) varies between 115,3 and 122,6 % depending on the inventory management assumption made. The model is not sensitive to changes in rating limits, i.e. no combination supplier/item changed and only somewhat sensitive to changes in weights. The sensitivity analyses resulted in 1 and 4 changes in combinations supplier/item on 33 for changes in weights within and between category respectively.

Thompson (1990) introduces Monte Carlo simulation to reduce the uncertainty innate to the rating mechanism. Ratings can be simulated using a uniform or a triangular distribution. The interpretation of the resulting distribution of scores happens by judging modus, variance and overlap. Giving weights to the various criteria remains a subjective process. Only uncertainty related to the rating process itself is dealt with in this model. Soukup (1987) introduces uncertainty related to the requirements. Quite strange, in the Thompson paper, only qualitative criteria are rated and in the presented example no price variable is included. To evaluate the TCO of this model we have made a simulation for the ratings from a uniform distribution, using scores on compatibility of systems (EDI), service and delivery reliability. From table 2, we see that the TCO of Thompson (1990) varies between 115,3 and 122,6 % depending on the inventory management assumption made.

Willis, Huston and Pohlkamp (1993) use "dimensional analysis" in a single item model where a series of pairwise comparisons are made among suppliers using a Vendor Performance Index, defined as follows:

$$VPI = \sqrt[w]{\prod_{i=1}^{n} \left(\frac{X_i}{Y_i} \right)^{w_i}}$$

with X_i and Y_i criterion performance score for supplier X and Y respectively,

w_i weight assigned to criterion i and

w sum of all weights.

The advantage of this method is that each criterion can be measured in its own units, but the rating and weighting system remains highly subjective. Also it is impossible to obtain a zero score on a criterion since division by zero is not defined. For the application to the ball bearings case, in the philosophy of the paper, we have used the criteria price, delivery reliability, ease of ordering (EDI) and service. The TCO of Willis, Huston and Pohlkamp (1993) varies between 114 and 121,3 % depending on the inventory management assumption. Their model proves to be insensitive to changes in weights and ratings, i.e. no combination supplier/item changed.

Li, Fun and Hung (1997) have published a paper in reaction to the Willis, Huston and Pohlkamp (1993) paper in which they describe the disadvantages of the VPI. Alternatively, they propose a fuzzy sets methodology by introducing the SUR index that takes the inconsistency of the evaluator into account for each qualitative criterion. If we apply this approach to the criteria proposed in Willis et al. (1993) the TCO varies between 113,7 and 121 % depending on the inventory management assumption, which is slightly better than the TCO of Willis et al. (99,7%). We have observed that the sensitivity to changes in weights and ratings is very high with 11 and 18 changes on 33 respectively, surely compared to that of the Willis et al. model. If we apply the Li et al. methodology ànd their proposed criteria to the ball bearings case, using ratings on price, delivery and flexibility without the specific compensation for judgement since there are no data available for this case, we find TCO between 113,2 and 120, 4 %. Our sensitivity analyses indicate that the model remains very sensitive to changes in weights and ratings with 12 and 15 changes on 33 respectively. Observe from table 2 that all these single item rating models without inventory management overestimate the return on supplier level and the cost on unit level and underestimate the cost on order level. The cost on supplier level is underestimated because in most of the rating models the cost of the dedicated purchasing manager is not taken into account. The cost on order level is underestimated because of the one-period time frame. Many of the costs that are in fact varying with the number of orders are regarded in these single item rating models as driven by unit.

To the best of our knowledge three mathematical programming single item models without inventory management exist. Weber and Current (1993) use multi-objective goal programming to select vendors for a single item. When we apply this method to the ball bearings case we minimise two goals: net price and "bad service" which is the complement of service offered by the vendor. We have solved this goal programming problem using the lexicographic method that allows us to specify an ordered list of objectives. The GLEX command in LINDO (Schrage, 1995) first optimises the first objective. Given the optimal value for this objective, it then optimises the second objective subject to the first objective being equal to its optimal value, etc. No weights for the objectives have to be assumed. We find TCO of 100,5 and 107,7 % depending on the inventory management assumption. The supplier level returns and the order level costs are underestimated. Weber and Current (1993) use a value path analysis to graphically display the results.

Weber and Desai (1996) use Data Envelopment Analysis to evaluate the efficiency of vendors with the aim of improving the negotiation process for the single item. As they mention themselves, the DEA methodology doesn't provide any insights for the suppliers that are on the efficient frontier. Problem for the application of DEA to the vendor selection or evaluation problem is that it is advisable that the number of input and output factors is small compared to the number of decision making units, in this case the number of suppliers. (Sexton, Silkman and Hogan, 1986) In a real life purchasing environment this rarely is the case because most of the time a lot of criteria are considered for a few vendors. When we applied the DEA methodology to the ball bearings case in the philosophy of the paper, we used two input factors, price and bad service, as defined infra, and one output factor, the purchasing of one unit of the item, compared to the other vendors. The cost of the purchasing managers' time to negotiate with a supplier could not be brought into the model since inputs have to be defined per single unit of the product. For most of the items two or three (up to four) suppliers were considered to be efficient by the DEA analysis. Since nothing can be said about efficient suppliers, the DEA methodology does not provide us with a strong mechanism to evaluate or select suppliers in this case. For only one item, the Degraeve and Roodhooft (1996) model chose a supplier that was inefficient according to the DEA. Although the model is meant to be a tool for supplier evaluation, we applied it to the supplier selection problem to be able to compare it with the other models. For those items for which several suppliers are considered efficient, we again used three possible assumptions, also used for the evaluation of the Timmerman (1986) model: (1) complete order with the efficient supplier with the lowest price, (2) split orders, each efficient supplier gets (1 / number of efficient suppliers) of the order quantity, and (3) TCO-optimal choice with the only additional condition that the supplier has to be efficient according to the DEA analysis. Again, the last assumption gives the most credit to the DEA model. Depending on the inventory management and splitting of order assumptions, TCO between 100,02 and 113,8 % are attained (table 2).

Chaudry, Forst and Zydiak (1993) develop linear and mixed binary integer programming models for a single item and take special interest in the modelling of price breaks, i.e. quantity discounts vs. surcharges, all-units vs. incremental discounts. The authors include constraints on quality level and delivery. Since for the ball bearings case there is no difference in quality, the delivery constraint is met by all vendors and there are no discounts available, the model simplifies to minimising net price. A TCO between 100,1 and 107,3 % is obtained depending on the inventory management assumption. The return on supplier level is underestimated.

Also, many of the mathematical programming multiple item models without inventory management simplify to minimising price for the ball bearings case (Rosenthal et al. 1995, Sadrian and Yoon 1994, Akinc 1993, Turner 1988). Rosenthal, Zydiak and Chaudry (1995) develop a multiple item mixed integer programming model for the special case in which suppliers offer discounted prices for bundled products. The same quality and delivery constraints as in Chaudry, Forst and Zydiak (1993) are added for every item.

Sadrian and Yoon (1994) propose a multiple item mixed integer programming model that is focusing on the modelling of business volume discounts. The so called "reliability costs" are not modelled. None of the optional constraints the authors propose, nor the volume discounts are relevant to the Cockerill Sambre case.

Akinc (1993) concentrates mainly on the number of suppliers. To start with, he proposes two models to obtain the extreme number of vendors. One model chooses the cheapest supplier for each item, what leads to the largest rational number of suppliers. The second model chooses the smallest number of suppliers that can deliver all items, disregarding cost. For the ball bearings case this number of suppliers is 6 and 1 respectively. Then, model one and two support model three in which the trade-off between number of suppliers and cost is analysed. A number of heuristics are proposed to make the model workable for large data sets. Since in the case of Cockerill Sambre there is no difference on the quality or delivery criterion, also this model results into minimising prices.

Turner (1988) describes the linear programming routine for the multiple item problem of British Coal. Instead of solving the integer problem, the LP formulation is repeated in an interactive manner to allow the purchasing managers to check on several possible solutions. Apart from price and discounts only capacity constraints and region limits are modelled. Since there are no discounts nor region limits in the Cockerill Sambre case, also Turner 's(1988) model simplifies to minimising net prices.

Current and Weber (1994) and Benton (1991) are the only two papers of the multiple item mathematical programming variety without inventory management that do not result into minimising prices.

Benton (1991) presents a heuristic procedure to solve the multiple item problem with a non-linear objective function with discontinuities that minimises the sum of ordering costs, holding costs and net price, giving special attention to the modelling of quantity discounts. He adds constraints on the total inventory investment and the warehousing space occupied. Since in the ball bearings case there are no quantity discounts, nor constraints on inventory investment or space, this single time period model simplifies to minimising the sum of price, ordering and holding costs. TCO of 107,3 and

100,1% are obtained depending on the inventory management assumption. The return on supplier level is underestimated.

Current and Weber (1991) make an application of facility location modelling constructs to the vendor selection problem. First they formulate the Single Plant Location Problem (SPLP) as a vendor selection model minimising the sum of fixed costs and "actual purchasing" costs. The decision variables are the fraction of item i's demand purchased from vendor j and a binary variable that denotes whether vendor j is selected or not. Expediting costs and internal processing costs are classified with the fixed costs, though they are dependent on the number of orders, set ups and others in multiple time frame models. Because the SPLP formulation doesn't take inventory management into account these costs are underestimated. For the application to the ball bearings case, fixed costs are the sum of contract set up, internal processing, ordering and invoicing costs. TCO of 107,3 and 100,1% are obtained depending on the inventory management assumption. They also propose a SPLP formulation with the minimisation of late deliveries, but this is irrelevant to our case. Also, this model sums two different units, namely number of units and cost in a currency. Second, they propose a model based on the p-Median Location Problem (PMLP). The decision variables are the same as in the SPLP formulation. After removing a typo in the objective function (a_i has to be removed or else the unit would be quantity^2) and adding a constraint that forces at least one unit to be ordered from a selected supplier, the formulation is identical to the SPLP case except for fixing the desired number of suppliers. The constraint has to be added because by fixing the number of suppliers the program could add the fixed cost of a selected supplier without ordering anything because of the high variable cost. The evaluation of the PMLP model is made in comparison to the TCO model with a fixed number of suppliers. TCO varies between 100,1 and 107,3 %. Finally, they introduce the Set Covering Location Problem (SCLP) minimising the number of suppliers, assuming that total cost and price are unimportant. A disadvantage of this model is that it can not select suppliers when more than one supplier is able to deliver all the desired products. When applied to the Cockerill Sambre case one single supplier is selected since only this supplier is able to deliver all the types of ball bearings. TCO of 122,6 and 115,3 % are obtained depending on the inventory management assumption. All the Current and Weber (1994) models underestimate the return on supplier level and the cost on order level.

6. Conclusions and Suggestions for Future Research

Several conclusions can be drawn from table 2, given the Total Cost of Ownership perspective. First, it is clear that all mathematical programming models perform better than the rating models because they approach the problem in a more objective way by optimising an explicitly stated objective function. Second, except for the Weber and Desai (1996) DEA methodology that only throws out the worst vendors as being inefficient in this case, multiple item vendor selection models perform equally good or better than single item models. Single item models fail to take into account the interdependencies among the different products. A supplier can be offering a larger discount based on total sales volume, irrespective of the product mix. Order level costs could be minimised by combining orders for several products into one single order form. Single item rating models are always performing worse than multiple item mathematical programming models. Third, it is a good strategy to incorporate inventory management into the vendor selection decision. For example, at the order level, costs can differ substantially among the different suppliers due to the possibility of ordering via EDI. If, due to inventory management reasons frequent ordering is necessary, a supplier with a low unit price but a high order cost (e.g., no EDI), can generate a higher Total Cost of Ownership than a supplier with a higher unit price and an EDI-system. Another example is the trade-off between the receiving a quantity discount and the inventory holding costs when buying larger lotsizes. Fourth, it is not rewarding to fix in advance the number of suppliers to use. There is no unequivocal relationship between the number of suppliers and the TCO. Fifth, different levels in the Activity Based Costing hierarchy are under- or overestimated in the different vendor selection models. All the single item rating models without inventory management overestimate the return on supplier level and the cost on unit level and underestimate the cost on order level. The multiple item mathematical programming models underestimate the return on supplier level. All the models without inventory management underestimate order level costs seriously and overestimate unit costs, under the assumption that everything is bought in the first period.

Future research should be conducted in developing multiple item mathematical programming vendor selection models with inventory management, since the simultaneous decision to select vendors and to determine order quantities seems to be saving on Total Cost of Ownership. A second fruitful path for future research is to introduce uncertainty with respect to requirements, deliveries, quality, prices etc. indecision models. The same methodology can also be applied to other real life data sets to check whether the conclusions remain stable. At the moment the authors are working on a very extensive data set of Alcatel Bell.

table 1: Classification of Vendor Selection Models

single item		multiple item			
without inventory management over time		without inventory management over time		with inventory management over time	
rating/linear weighting	mathematical programming	rating/linear weighting	mathematical programming	mathematical programming	statistical
Timmerman (1986) Gregory (1986) Barbarosoglu & Yazgaç (1997) Willis, Huston & Pohlkamp (1993) Li, Fun & Hung (1997) Soukup (1987) Thompson (1990)	Chaudry, Forst & Zydiak (1993) Weber & Current (1993) Weber & Desai (1996)	Grando & Sianesi (1996)	Turner (1988) Current & Weber (1994) Akinc (1993) Sadrian & Yoon (1994) Rosenthal, Zydiak & Chaudry (1995) Benton (1991)	Bender, Brown, Isaac & Shapiro (1985) Degraeve & Roodhooft (1996)	Ronen & Trietsch (1988)

table 2: Evaluation of Vendor Selection Models from a Total Cost of Ownership Perspective - Results

	Total Cost of Ownership %	Supplier Level Cost %	Order Level Cost %	Unit Level Cost %
Degraeve & Roodhooft	100	100	100	100
Timmerman as. period 1 & split orders	115,53	179,40	16,67	116,85
Timmerman as. period 1 & lowest price	114,72	175,75	16,67	115,98
Timmerman as. period 1 & TCO optimal	114,72	175,75	16,67	115,98
Timmerman as. TCO optimal & split orders	108,33	179,40	87,5	109,73
Timmerman as. TCO optimal & lowest price	107,53	175,75	100	108,86
Timmerman as. TCO optimal & TCO optimal	107,53	175,75	100	108,86
Gregory as. period 1	122,58	217,61	2,08	124,52
Gregory as. TCO optimal	115,33	217,61	12,5	117,40
Thompson as. period 1	122,58	217,61	2,08	124,52
Thompson as. TCO optimal	115,33	217,61	12,5	117,40
Willis, Huston & Pohlkamp as. period 1	121,29	211,13	4,17	123,12
Willis, Huston & Pohlkamp as. TCO optimal	114,04	211,13	18,75	116,00
Li, Fun & Hung on ex. Willis as. period 1	120,95	209,01	4,17	122,75
Li, Fun & Hung on ex. Willis as. TCO optimal	113,71	209,01	25	115,63
Li, Fun & Hung as. period 1	120,39	201,30	4,17	122,05
Li, Fun & Hung as. TCO optimal	113,15	201,30	25	114,93
Weber & Current as. period 1	107,65	95,02	20,83	107,48
Weber & Current as. TCO optimal	100,49	95,02	125	100,36
Weber & Desai as. period 1 & lowest price	107,30	91,31	20,83	107,06
Weber & Desai as. period 1 & split order	113,76	148,94	20,83	114,52
Weber & Desai as. period 1 & TCO optimal	107,18	100,01	20,83	107,12
Weber & Desai as. TCO optimal & lowest price	100,13	91,31	125	99,94
Weber & Desai as. TCO optimal & split order	106,54	148,94	68,75	107,40
Weber & Desai as. TCO optimal & TCO optimal	100,02	100,01	125	99,99
models that simplify to minimising price as. period 1	107,30	91,31	20,83	107,06
models that simplify to minimising price as. TCO optimal	100,13	91,31	125	99,94
Benton as. period 1	107,30	91,31	20,83	107,06
Benton as. TCO optimal	100,13	91,31	125	99,94
Current & Weber SPLP as. period 1	107,32	91,12	14,58	107,09
Current & Weber SPLP as. TCO optimal	100,13	91,12	87,5	99,97
Current & Weber PMLP as. period 1 supl #6	107,29	91,29	16,67	107,07
Current & Weber PMLP as. period 1 supl #5	107,30	91,29	16,67	107,07
Current & Weber PMLP as. period 1 supl #4	107,31	91,28	16,67	107,07
Current & Weber PMLP as. period 1 supl #3	107,30	91,26	16,67	107,04
Current & Weber PMLP as. period 1 supl #2	107,06	95,73	16,67	106,85
Current & Weber PMLP as. period 1 supl #1	106,28	100	16,67	106,07
Current & Weber PMLP as. TCO optimal supl #6	100,12	91,29	100	99,95

Current & Weber PMLP as. TCO optimal supl #5	100,12	91,29	100	99,95
Current & Weber PMLP as. TCO optimal supl #4	100,12	91,28	100	99,95
Current & Weber PMLP as. TCO optimal supl #3	100,12	91,26	100	99,95
Current & Weber PMLP as. TCO optimal supl #2	100,07	95,73	100	99,98
Current & Weber PMLP as. TCO optimal supl #1	100	100	100	100

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